THE PROP92 FOURIER BEAM PROPAGATION CODE

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Introduction

Numerical simulations of the laser beam propagation[1] have been used in designing and optimizing all of LLNL's high-power lasers for inertial confinement fusion (ICF). The architecture and design of the laser for the National Ignition Facility (NIF) were determined and optimized using a suite of new codes including CHAINOP, BTGAIN, and PROP92.

CHAINOP[2] is a very fast lumped-element energetics code with an extensive cost database, a choice of optimization algorithms, and a set of heuristic rules for diffraction and nonlinear effects and for operational constraints.

BTGAIN[3] is a far-field model based on the Bespalov–Talanov theory[4] for the linearized growth of decoupled single-mode beam perturbations in a nonlinear medium. Itincludes Frantz–Nodvik saturated gain, the facility to input beam perturbations of arbitrary spectral content at each component, and a postprocessor that can construct near-field beam statistics.

PROP92 was originally written and released by R. G. Nelson[5] in 1992, with advice and assistance from J.B. Trenholme. It isa full-featured optics propagation and laser simulation code. Internal models are included for most of the components in the optical amplifier and transport system. A Fourier technique is used to solve the nonlinear Schrödinger (NLS) equation,yielding a representation of the (single-polarization)complex electric field in two transverse directions plus time (2D) as the beam transports through andisaffectedby the optical elements. Alternatively, PROP92 can also operate in 1-D planar or 1-D circularly symmetric modes. In the latter case, Hankel/Besseltransformsare usedinsteadof Fourier transforms. Average wavefront curvature is explicitly removed in the Talanov transformation. Both gain and nonlinear index effects are calculated in the near field with a split-step approach. Propagation is done in the far field.

In this article, we describe the algorithms and structure of the PROP92 code. We discuss 2-D operation, since the restriction to either 1-D planar or 1-D circular is straightforward.

Vacuum Propagation Algorithm

PROP92 describes the laser beam in terms of a complex electric field, $\mathbf{E}(x,y,z,t)$. The dominant plane-wave portion of the beam and its center-point position, tilt, and curvature are all explicitly removed to define a wave function u for numerical evaluation

$$\begin{aligned}&\mathbf{E}(x,y,z,t)\\&=\mathbf{e}e^{i(k_0 z-\omega_0 t)}e^{i[\bar{\kappa}_x(x-x_0)+\bar{\kappa}_y(y-y_0)]}e^{-ik_0(x-x_0)^2/2R(z)}\\&\times e^{-ik_0(y-y_0)^2/2R(z)}u(x,y,z,t)\ .\end{aligned}\tag{1}$$

In Eq. (1), the laser's optical frequency is ω_0, and the wave number is $k_0 = n_0\omega_0/c$, where n_0 is the index of refraction of the medium through which the beam is propagating, and c is the vacuum speed of light. The average tilt on the wavefront is described by the quantities $\bar{\kappa}_x$ and $\bar{\kappa}_y$, and the central position (x_0,y_0) satisfies

$$\begin{aligned}x_0(z+\delta z)&=x_0(z)+\bar{\kappa}_x\,\delta z/k_0\\y_0(z+\delta z)&=y_0(z)+\bar{\kappa}_y\,\delta z/k_0\ .\end{aligned}\tag{2}$$

R is the average wavefrontcurvature, with the convention that positive R corresponds to a focusing wave. It satisfies

$$R(z+\delta z)=R(z)-\delta z\ .\tag{3}$$

The complex wave function u is represented on a regular rectangular grid

$$u_{j,k} = u(x_j + x_0, y_k + y_0, z, t) \quad , \tag{4}$$

where j and k are integers in the range $-N_x/2 \le j < N_x/2$, $-N_y/2 \le k < N_y/2$, $x_j = jL_x / N_x$, $y_k = kL_y / N_y$, L_x and L_y are the physical dimensions of the calculational grid, and N_x and N_y are the number of grid points.

In a linear medium (no gain, no nonlinear index effects), the electric field obeys the wave equation

$$\nabla^2 \mathbf{E} - \frac{n_0^2}{c^2}\frac{\partial^2}{\partial t^2}\mathbf{E} = 0 \quad . \tag{5}$$

Using Eq. (1) and applying the slowly varying ($\partial u/\partial t << \omega_0 u$) and paraxial ($\partial^2 u/\partial z^2 << k_0 \partial u/\partial z$) approximations, we find that u translates as

$$u(\mathbf{r}, z+\delta z) = \frac{R_0}{R}\int \frac{d^2\kappa}{(2\pi)^2} e^{i\frac{R_0}{R}\kappa\cdot\mathbf{r}} e^{-\frac{iR_0}{2k_0R}\kappa^2\delta z} \times \int d^2\mathbf{r}'\, e^{-i\kappa\cdot\mathbf{r}'} u(\mathbf{r}', z, t) \tag{6}$$

where $R_0 = R(z)$, and $R = R(z+\delta z)$. In Eq. (6), we can see the familiar Fourier propagation algorithm: (a) Fourier transform, (b) multiply each Fourier mode by a phase that is linear in propagation distance and quadratic in angle, and (c) inverse transform. Because u is represented on a discrete mesh, the continuous transform in Eq. (6) is replaced by a discrete fast Fourier transform (FFT). This means that the field is actually represented by a function that is periodic in both near-field and far-field coordinates. The effective grid dilatation apparent in the inverse transform is actually carried out in PROP92 by changing the values of L_x and L_y at the new observation point $z + \delta z$. Scaling the computational grid tends to maintain resolution for focusing beams (which would otherwise occupy progressively less of the grid) and avoids aliasing of defocusing beams (which would otherwise try to outgrow the grid and thus "wrap" information around the edges). The prefactor, R_0/R, may be thought of as scaling the intensity to conserve energy as the transverse extent of the beam changes.

Nonlinear Self-Focusing

In centro-symmetric (invariant under inversion through the origin) and isotropic materials, the single-frequency wave equation may generally be written as

$$\left(\nabla^2 + \frac{n^2(E)\omega^2}{c^2}\right)\mathbf{E} = 0 \quad , \tag{7}$$

where the field-dependent refractive index is

$$n(E) = n_0 + \frac{1}{2}n_2E^2 + \ldots \quad . \tag{8}$$

Applying the slowly varying wave and paraxial approximations yields the NLS equation

$$\left[\frac{\partial}{\partial z} - \frac{i}{2k_0}\nabla_T^2 - \frac{2\pi i}{\lambda_{\text{vac}}}\gamma I\right]u = 0 \quad , \tag{9}$$

where $\gamma = n_2/(n_0 c\varepsilon_0)$, λ_{vac} is the vacuum wavelength, and $I = n_0 c\varepsilon_0 |u|^2/2$ is the local irradiance. The parameter γ is a material property that measures the field phase advance per unit of intensity and per unit of length. Because n_2 and γ are positive for materials of interest, local high-intensity perturbations create their own focusing phase perturbations, thereby amplifying the perturbation, and ultimately leading to catastrophic filament collapse. Equation (9) is written with the intensity explicitly introduced because in PROP92, the electric field is normalized such that $|u|^2 = I$. As presented, Eqs. (5), (6), and (9) are not affected by this normalization choice.

In PROP92, nonlinear propagation effects are computed by a split-step algorithm. The propagation through the nonlinear medium is divided into a number of steps of length δz. Vacuum propagation steps [Eq. (6)] are alternated by thin-optic transformations,

$$u(x,y,z) \leftarrow u(x,y,z)e^{i\Delta B(x,y,z)} \quad ,$$

where

$$\Delta B(x,y,z) = \frac{2\pi\gamma}{\lambda_{\text{vac}}}|u(x,y,z)|^2\delta z \quad . \tag{10}$$

For higher-order accuracy, the process is "leapfrogged," with a diffraction step of length $\delta z/2$ at the beginning and end of the nonlinear optic.

Research shows that PROP92's split-step algorithm agrees with experimental results both at 1ω and at 3ω[6,7] when sufficient resolution is included in the calculation. There are, however, two difficulties with simply relying on the propagation algorithm for computing all self-focusing threats:

1. Catastrophic self-focusing cannot occur in 1D,[8] but time and resource constraints require that we use PROP92's 1-D planar mode for much of our design optimization.[9,10]

2. Even in 2D, it is often not feasible to adequately resolve beam features at the sizes that are most prone to self-focusing amplification.

Given these difficulties, we have recently added[11] a number of features to the code to warn users about filamentation danger.

Sulem et al. have shown[12] that intensity perturbations of the most unstable size and shape will collapse, during propagation through a uniform nonlinear medium, in a distance such that $\Delta B_0 = \gamma I_0 \Delta z = 2.3$, where I_0 is the maximum intensity at the peak of the initial perturbation. By detecting and reporting the maximum over the transverse position of the ΔB through the thickness of any given optic, PROP92 tracks the safety margin with respect to collapse in that optic. To allow for optical gain (also calculated by a split-step algorithm), the maximum $\Delta B(x,y)$ is recalculated from the current z-position to the exit face of the optic at each z-step.

Before the NLS becomes singular, the collapse process is limited by nonlinear processes, such as optical breakdown (not included in the model). These breakdown processes led to the “angel hair” tracks in the Nova and Beamlet high-power optics. PROP92 has a test for breakdown-induced tracking, based on an extrapolation of the peak irradiance in the beam. Trenholme[13] has numerically verified that during the filamentation process, all perturbations evolve to a shape resembling the “ground state” (which collapses most rapidly) and that late in the collapse the intensity scales as $(z_c - z)^{-4/3}$, where z_c is the position of the singular collapse point. At each z-step through the slab, the maximum calculated intensity is scaled by $[z_c/(z_c - z_{exit})]^{4/3}$ to project a maximum anticipated self-focused intensity in the slab. A warning message is printed if this projected intensity exceeds a user-entered breakdown intensity.

Finally, PROP92 includes a check on the adequacy of the grid spacing to resolve the most important structure. This check is based on the Bespalov–Talanov (BT) theory of the linearized growth of independent Fourier modes.[3,4] If we expand u as

$$u(x,y,z) = u_0\left[1 + \sum_{\alpha^*_{-\kappa}} \alpha_\kappa(z)\, e^{i\kappa\cdot r}\right] , \tag{11}$$

substitute u into Eq. (9), and drop terms of order α^2, we find that α_κ and are coupled, and they grow such that

$$\begin{pmatrix} \alpha_\kappa(z) \\ \alpha^*_{-\kappa}(z) \end{pmatrix} = \begin{bmatrix} \cosh S\Theta - i\dfrac{\Theta - B}{S\Theta}\sinh S\Theta & i\dfrac{B}{S\Theta}\sinh S\Theta \\ -i\dfrac{B}{S\Theta}\sinh S\Theta & \cosh S\Theta + i\dfrac{\Theta - B}{S\Theta}\sinh S\Theta \end{bmatrix} \begin{pmatrix} \alpha_\kappa(0) \\ \alpha^*_{-\kappa}(0) \end{pmatrix} , \tag{12}$$

where

$$\Theta = \kappa^2 z / 2k_0$$

$$B = \gamma u_0^2 z$$

$$S = \sqrt{1 - 2B/\Theta} . \tag{13}$$

Defining the mode amplitude as $|\alpha_\kappa|^2 + |\alpha_{-\kappa}|^2$, maximum gain at given κ occurs when

$$\alpha^*_{-\kappa} = e^{-i\varphi}\alpha_\kappa$$

$$\varphi = \frac{\pi}{2} + \tan^{-1}\left[\frac{\Theta - B}{S\Theta}\tanh S\Theta\right] . \tag{14}$$

This maximum modal gain is

$$G = 1 + \frac{2B^2}{(S\Theta)^2}\sinh^2 S\Theta + \frac{2B}{S\Theta}\sinh S\Theta\sqrt{1 + \frac{B^2}{(S\Theta)^2}\sinh^2 S\Theta} . \tag{15}$$

Maximizing G with respect to Θ, we find that the mode with maximum growth according to BT is

$$\Theta_{max} = B \tag{16}$$

PROP92 issues a warning if the spatial frequency of this mode is greater than the Nyquist frequency $\kappa_{Ny} = 2\pi \min(N_x / L_x, N_y / L_y)$.

Optical Damage

Besides tracking caused by nonlinear self-focusing, which leads to superhigh intensity and plasma formation, large optical *fluence* can lead to optical damage ranging from color-center formation to material fracture. So far, there is no adequate explanation of what causes the formation of these damage sites. However, Campbell et al. have compiled[14] an extensive experimental database of damage fluences for various materials during their exposure to nearly Gaussian pulses of various pulse lengths. When the pulse length is between about 10 ps and about 100 ns, the data are consistent with the scaling

$$\Phi_D = C\tau^{\beta} \quad , \tag{17}$$

where Φ_D is the fluence at which damage sites first appear, τ is the Gaussian pulse width, and C and β are material-dependent constants. In particular, β ranges between about 0.3 and 0.5 for the various materials of interest and is independent of τ, for a given material, over 4 to 5 decades of pulse duration.

For many applications, such as driving ICF targets on NIF, it is necessary to subject optical materials to high fluence with a temporal pulse history that does not resemble Gaussian. To assess the danger of optical damage from such pulses, we have implemented a phenomenological diffusion-like model,[15] for damage from arbitrarily shaped pulses.

The model assumes that damage is related to the accumulation of some quantity D whose source is proportional to the local laser irradiance, and which accumulates with a diffusive kernel. Damage is presumed to occur instantly if D exceeds some material-dependent critical value D_D. Trenholme demonstrated that no true diffusion model in 1, 2, or 3 dimensions can match the observed data. Rather, he was led to posit a form,

$$D(t) = A\int_0^{\infty} \frac{I(t-s)}{s^{d/2}}\, ds \quad , \tag{18}$$

where d is an effective dimensionality, I is the local irradiance, and A is a constant. Although Eq. (18) is formally singular when $d \geq 2$, this is not important because all existing damage data correspond to $d \leq 1$. Equation (18) is related to the measured data by substituting for I, a Gaussian with peak value I_D and full width at half maximum τ. Evaluating the maximum over t of the resulting damage integral gives

$$D_D = I_D A \tau^{1-d/2} \max_{\xi} \int_0^{\infty} \frac{\exp\left[-4\ln 2(\xi - s)^2\right]}{s^{d/2}}\, ds \quad , \tag{19}$$

where, for given d, the maximum of the integral is simply a number that can be evaluated once numerically, and the scaling with τ is explicit. Evaluating the fluence, Φ_D, for the same Gaussian pulse and setting it equal to $C\tau^{\beta}$ identifies d as 2β and yields

$$D_D = \frac{AC}{\sqrt{\pi}} (4 \ln 2)^{\beta/2} \max_{\xi} \int_0^{\infty} \frac{e^{-(\xi - s)^2}}{s^{\beta}}\, ds \quad . \tag{20}$$

For each optic for which damage calculations are desired, the experimental scaling values C and β are input to PROP92. Equation (20) is then evaluated, and the limit value of the damage integral is stored. Each time that the beam passes that point in the laser chain, the damage integral [Eq. (18)] is evaluated for each spatial grid point on the calculational mesh. The maximum of the ratio D/D_D is reported. If that maximum is greater than one, a warning is issued and the damaged area fraction is reported. Note that the constant A drops out of this calculation.

Laser Component Models

PROP92 is a general-purpose computational tool for simulating the operation of laser chains and for optimizing their performance. To enable this process, it contains a library of models of the components that make up the chain and a sequencer that controls the order in which the beam encounters each of these modules. In 2D, the beam is stored as an $N_x \times N_y \times N_t$ array of complex numbers. We have already described how the propagation between components is modeled as an inverse FFT of a phase times an FFT of this array. We have also described how the array is diagnosed to assess the danger of filamentation or optical damage. In this section, we describe the transformations we use to model some of the more important optical components that comprise typical laser chains.

Slabs

In PROP92, a slab is a region of space, of length Δz, filled with a uniform medium of given n_0 and γ, with given small-signal gain G (at small input fluence, Φ_{in}, the output fluence is $G\,\Phi_{in}$), saturation fluence Φ_{sat}, and transmissivity T. If the gain is not unity, then gain typically depends on the transverse coordinates and evolves as part of the propagation algorithm.

Propagation through slabs is modeled by a split-step process, with the step size δz ($\Delta z/\delta z$ = integer) specified by the user. A propagation step with length $\delta z/2$ is followed by the application of nonlinear phase $B(x,y,\delta z)$ and a gain calculation (described below) that also correspond to length δz. After that, propagation steps of length δz are alternated with near-field effects corresponding to δz. A final propagation of length $\delta z/2$ completes the slab. Transmissivity is applied as a field multiplier at the slab entrance and exit.

The gain calculation is a simple Frantz–Nodvik[16] transformation. The initial slab gain $G(x,y)$ is divided equally among the z-slices—each has gain $g(x,y,z) = G(x,y)\,\delta z/\Delta z$. This array of real numbers is stored on disk and read into memory successively as needed. At each spatial point, the temporal dependence of the field is thought of as a sequence of piecewise-constant values, so a fluence $\Phi_j = |E(x,y,t_j)|^2 \delta t_j$ can be associated with each time slice. As the j^{th} time slice at x,y passes through the gain slice at x,y,z, the Frantz–Nodvick model for a two-level, homogeneously broadened laser line is

$$\Phi_{\text{out}} = \Phi_{\text{sat}} \ln\left[1 + g\left(e^{\Phi_{\text{in}}/\Phi_{\text{sat}}} - 1\right)\right]$$

$$g_{\text{out}} = \frac{g_{\text{in}}}{g_{\text{in}} - e^{-\Phi_{\text{in}}/\Phi_{\text{sat}}}\left(g_{\text{in}} - 1\right)} \quad . \tag{21}$$

The field for this time slice is scaled to the new fluence, and the gain distribution for this z-slice is overwritten by the new values so that the slab is cumulatively saturated.

Aberrations

PROP92 is capable of imposing a variety of phase aberrations on the field. Included are the low-order Seidel aberrations tilt, focus, astigmatism, spherical, and coma. Also, phase ripples,

$$E \leftarrow E e^{2\pi i a \cos(\mathbf{q}\cdot\mathbf{r}+\chi)} \quad , \tag{22}$$

can be applied at arbitrary amplitude, scale length, transverse direction, and phase. Another possibility is random phase noise with specified peak-to-valley amplitude and correlation length. Finally, an arbitrary phase-shift distribution can be specified numerically.

Lenses

A lens is treated as a combination of a slab (with unity gain but with some thickness and given linear and nonlinear indices) and a thin lens transformation,

$$R \leftarrow \frac{Rf}{R+f} \quad . \tag{23}$$

Lens aberrations must be specified as separate "aberration" components.

Spatial Filters

A spatial filter consists of two focusing lenses of focal lengths f_1 and f_2, separated by a distance $f_1 + f_2$, and a pinhole at the common focal plane. In a laser chain, spatial filters fulfill three important functions. First, since the field at the lens focal plane is a dimensional-scale and an intensity-scale of the incoming field's Fourier transform, the pinhole strips off the high-spatial-frequency portions of the beam. Otherwise the beam would be more prone to self-focusing. Second, in passing through the filter, the beam's transverse dimensions are magnified by the factor $m = f_2/f_1$, with a corresponding change in irradiance. Third, since an object at distance d before the filter is imaged at a distance $m(f_1 + f_2 - md)$ after the filter, the evolution of long-scale-length phase noise into amplitude modulation is inhibited by proper placement of filters in the system.

Spatial filters can be treated as a sum of their constituent parts: a lens transformation, followed by a propagation of length f_1, clipping at the pinhole, propagation by f_2, and another lens. As long as the beam entering the filter is not focusing or defocusing, it is rigorously correct to use the lumped-element transformation implemented in PROP92 instead. The lumped-element transformation consists of clipping the Fourier transform of the field array, propagating through a negative distance $-(f_1 + f_2)/m$, magnifying the beam by m, and spatially inverting the beam in the transverse plane $E(x,y) \leftarrow E(-x,-y)$. PROP92 offers a variety of options for pinhole sizes, shapes, orientations, and transverse offsets (including the option to describe the filter function numerically). The pinhole edge is smoothed over several transverse grid steps to avoid aphysical numerical ringing.

Mirrors

Mirror components reverse the logical direction that the beam sequencer traverses chain components, enabling us to model multipass architectures. Tilts on the mirrors are permitted, affecting $\bar{K}_x$ and $\bar{K}_y$ in Eq. (1), and thereby affecting the beam's average transverse position as it samples aberration and gain fields. Recently, Henesian has added a model for phase-conjugating mirrors, including an intensity-thresholding effect.

Masks and Obscurations

Both masks and obscurations modify the beam by applying a near-field intensity filter that varies with transverse position. Both offer a number of built-in shapes and orientations. They offer control over the degree of edge smoothing, and both offer the option for numerical description of the filter function. A mask represents a filter that passes the center of the beam and removes the edge (such as would occur because of the finite physical aperture of chain components). An obscuration removes some small portion of the center of the beam (such as would occur if the beam struck a small obscuration). Obscurations also offer the option of applying a specified phase to a portion of the beam, to represent, for example, regions of surface irregularity or of bulk index variation.

Adaptive Optics

Adaptive optics are used in laser systems to correct for long-scale-length aberrations induced on the beam. At some point in the chain, the beam reflects from a deformable mirror. The mirror's surface can be distorted by as much as several wavelengths by displacing an array of mechanical actuators. At another point, a phase sensor is located. Operation of the adaptive optic consists of adjusting the displacement of the mirror actuators to minimize the transverse variation of the phase at the sensor.

On NIF, the deformable mirror is one of the end mirrors in the multipass cavity. Phase is detected by a Hartmann sensor, which consists of a lenslet array (on NIF it will be triangular) and a light sensor capable of detecting the centroid of the focal spot from each lenslet. The operational algorithm attempts to minimize the sum of the squares of the focal spot displacements. A transfer matrix is measured by observing the spot movements resulting from small travel of each of the actuators. A matrix inversion then predicts the actuator displacements necessary to best cancel a measured set of spot displacements. By placing this correction procedure into a feedback loop, continuous correction for time-varying effects (such as air-path turbulence and decaying thermal sources) has been accomplished.[17]

Modeling the correction procedure has two parts: (1) determining the beam phase modification accompanying a given set of actuator displacements and (2) finding the best set of displacements to use. For the first part, we have implemented a model where the mirror surface (hence the applied phase field) is assumed to be a sum of Gaussians,

$$\varphi(x, y) = \sum_j a_j e^{-\left|\mathbf{r}-\mathbf{r}_j\right|^2/\sigma^2} \quad . \tag{24}$$

In Eq. (24), the sum is over the set of actuators, $\mathbf{r}_j$ are the set of centersof influence (nearlythe sameasthe physical actuator positions), σ is the influence width, and the source strengths a_j are related to the actual actuator displacements. Typically, the $\mathbf{r}_j$ are located on a regular triangular or rectangular array with some outward displacement for the sources on the array boundary caused by their nonhomogenous environment. The values of $\mathbf{r}_j$ and σ are inputs to PROP92's adaptive-optic model. In one of its modes of operation, the a_j are also input parameters, in which case the component is modeled as a determined phase modification. This form of operation allows optimization of the best set of source strengths to meet some external objective, for example maximizing the energy into a hohlraum laser entrance hole.

In another mode of operation, PROP92 can adjust the a_j to apply a best local phase correction in minimizing the fluence-weighted mean square deviation from flat phase. "Adapt" components that are multipassed retain the shape that is determined the first time they are encountered. This method, since the phase correction is local and simply determined, is useful for obtaining a quick and reasonably accurate approximation of the performance enhancement that might be expected.

Although it is not strictly part of PROP92, Henesian has built up a realistic model of the adaptive optic operation as it will be implemented on Beamlet and NIF.[18] At the end of a PROP92 simulation of a chain, the field array is dumped to disk. This file is read by a postprocessor routine that simulates the action of the Hartmann sensor. Portions of the array are masked off and brought to focus, and the centroid of each focal spot is calculated. If there are N_a actuators, then N_a separate PROP92 runs are required to determine the transfer matrix, which is easily inverted (or SV decomposed if, as typically, it is nonsquare). For a given set of component aberrations, two more PROP92 runs suffice to measure the corrections required and to predict the performance with those corrections.

Plots

Considerable attention has been given to the graphical presentation of PROP92 results. At any point in the chain simulation, the user can display plots of near-field intensity, fluence, or phase—or of intensity or fluence either in the far field or in a partial focus region. These can be displayed as surface plots, contour plots, or cuts, either through specified position or through the maximum intensity point. The vertical scale can be linear or logarithmic. PROP92 has the capability to window the plots, which add resolution to a region of interest. As mentioned, PROP92 is capable of dumping the field array to disk, which enables us to use the graphical power of packages such as IDL for postprocessing.

Summary

PROP92 is a full-featured Fourier optics laser modeling, design, and optimization tool. It includes integrated models for a comprehensive set of optical elements and effects, as well as sophisticated algorithms for assessing the risk of optical damage and filamentation. As detailed elsewhere in this *Quarterly*, PROP92 predictions have been validated by comparison with Nova, OSL, and Beamlet experiments. Given reliable data on material properties and optical quality, we have confidence in PROP92's predictions of NIF performance.

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